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Analysis of Airworthiness Requirements for Commercial Aircraft Avionics System Design in Low Altitude Economy †

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Abstract: This paper introduces the development history and process of low altitude economy, explains the characteristics and advantages of low altitude economy, and further discusses the development direction and trend of commercial low-altitude aircraft. By analyzing the current popular commercial aircraft avionics system design features and considering the current low-altitude economic application scenarios, the characteristics of commercial low-altitude aircraft avionics systems design are described. Then, through the analysis of the design of low-altitude aircraft avionics systems, this paper puts forward the additional airworthiness requirements of commercial aircraft avionics system designs in low-altitude operation environments and explains the problems that should be paid attention to in the low-altitude operation application scenario. Through the research application of the airworthiness requirements of commercial aircraft avionics system design in the low-altitude economy, this paper provides guidance for the future development of low-altitude aircraft avionics systems.

Keywords: low altitude economic; commercial aircraft; avionics system; design airworthiness

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1. Introduction

At the beginning of the last century, with the vigorous development of aviation technology, the aviation industry gradually rose and formed a relatively complete commercial aviation system, which is mainly divided into public transport aviation and general aviation. Public transport aviation undertakes most commercial transport activities and establishes a relatively perfect commercial aviation support system. General aviation refers to commercial aircraft aviation activities other than public transport aviation [1]. General aviation mainly involves the special tasks of agriculture, fishery, forestry, and other industrial departments, such as flight operations and medical services, meteorological exploration, rescue and disaster relief, and cultural and sport emergency mission flight activities. However, due to the insufficient opening of low-altitude airspace in China, general aviation has been at a low level of development.

Since the State Council and the Central Military Commission jointly issued the Opinions on 'Deepening the Reform of China's Low-Altitude Airspace Management' in 2010 [2], the state and relevant functional departments had issued guiding documents on the low-altitude economy, especially in February 2021, when the Central Committee of the Communist Party of China and the State Council first issued 'the Outline of National Comprehensive Three-Dimensional Transportation Network Planning'. By improving the national comprehensive three-dimensional transportation network, a low-altitude economy ushered in explosive opportunities for development. A low-altitude economy is a comprehensive economic form based on low-altitude flight activities carried out by various manned and unmanned aircraft. Among them, traditional manned general aviation is an important part of the low-altitude economy, and the unmanned aerial vehicle is another important part of the low-altitude economy.

The development of a low-altitude economy focuses on a low-altitude flight, low-altitude support, low-altitude manufacturing, integrated services, and so on [3]. The core of a low-altitude economy is a low-altitude flight industry. For the healthy and rapid development of a low-altitude flight industry, the most concerning issues of a low-altitude aircraft industry (aircraft design and airworthiness safety supervision) need to be planned systematically. Aircraft include manned general aviation vehicles and unmanned aerial vehicles. Airworthiness safety supervision should take into account the operation of general aviation and unmanned aerial vehicles as a whole to form a reliable and applicable airworthiness safety supervision system. General aviation operations have accumulated some regulatory experience, such as CCAR23. However, low-altitude economy and general aviation have similarities. However, there are still many differences that need to be redefined in terms of aircraft design and airworthiness safety supervision, taking into account the existing experience of general aviation and the characteristics of unmanned aerial vehicles. The characteristics of low-altitude airspace operations are fully considered in the design of aircraft, and the adaptability development of aircraft is carried out. To sum up, if a low-altitude economy wants to develop in a healthy and orderly manner, it needs to focus on the low-altitude flight industry, the design of aircraft, and the supervision of airworthiness safety.

2. Development of Research Questions

In April 2010, *Anyang Daily* published the first news report on the 'low-altitude economy', and the low-altitude economy as a hot word has frequently appeared in various reports and academic forums [4]. Since then, domestic scholars have defined the concept of a low-altitude economy in 2011 and pioneered the definition of the theoretical basis of the existence of a low-altitude economy and its combination with real industries, forming a generalized low-altitude economic form [5]. Subsequently, with the application of new technologies (such as artificial intelligence, Internet of Things, etc.), the development of a low-altitude economy has entered a high-speed period. Domestic scholars have conducted in-depth research on the theory of low-altitude economy and the integration of industrial industries from different perspectives.

Domestic scholars have found that a 'low-altitude economy' is not a concept recognized by domestic scholars in foreign countries through searching authoritative English literature databases. Thus, the concept of a low-altitude economy is a creative vocabulary invented to solve the development of general aviation in China, and it is the result of rational utilization and allocation of low-altitude airspace resources [6]. The general aviation industry has a close relationship with the low-altitude economy, which can be said to be the product of general aviation industry upgrading, increasing the content of new aviation industry in low-altitude airspace so that a low-altitude economy can cover the whole industry chain in low-altitude areas.

At present, the main research results from domestic scholars focus on the definition of a low-altitude economic industry and the initial stage of industrial integration, but the research on the core aircraft of low-altitude flight and its airworthiness safety supervision is not enough. From the perspective of general aviation, this paper carried out analysis and research [7]. According to the characteristics of low-altitude airspace operation, methods to design aircraft systems and their airworthiness compliance specification requirements are urgently needed for an in-depth study of the problem. This paper analyzes the applicability of the design of typical avionics systems in different application scenarios of low-altitude operation aircraft and puts forward reasonable airworthiness safety supervision suggestions.

3. Aircraft Low Altitude Operation Scene

The low-altitude economic industry benefits from the application of new technologies and materials, and the core low-altitude flight business has formed a relatively complete low-altitude operation environment according to the design of low-altitude aircraft, the

production of low-altitude aircraft products, and the construction of ground systems. Combined with the needs of people's daily lives, such as tourism, agricultural production, logistics, urban management, transportation, intelligent networks, and so on, the low-altitude economic industry has its own characteristics after extending to different scenarios of low-altitude applications.

3.1. Low-Altitude Operation Scenarios to Support Tourism Consumption Systematic Literature Review

With the development of the low-altitude economy, low-altitude tourism is gradually accepted by people, and different levels of consumers begin to choose different low-altitude tourism products. For example, some people will choose low-altitude tourist transportation, some people will choose low-altitude sightseeing, and some people will select a low-altitude entertainment flight experience. Among them, the requirements of low-altitude tourism transportation and low-altitude tourism are not high, but the low-altitude entertainment flight experience puts forward high requirements for the aircraft. Most of the people who participate in low-altitude entertainment flight experiences are special groups who do not have rich driving experience. Based mainly on experience in the design of aircraft avionics systems, the display screen and navigation screen need to be simplified as much as possible to aid the operation personnel. In addition, to increase the monitoring and operation authority of the accompanying flight personnel, it is not possible to formulate a unified standard aircrew operation process like the aircraft operated on a route. According to the specific situation of the experienced flight personnel, it should be formulated by the accompanying flight personnel.

3.2. Low-Altitude Operational Scenarios to Support Agricultural Production Activities

China has a vast territory and used to be a major developed agricultural country in the world. Now, it is still a big agricultural country, and the development of agriculture is directly related to the rice bowl of the broad masses of the people. At present, domestic agriculture has a trend of scale, mechanization, and science and technology. Therefore, it is feasible and appropriate to use low-altitude aircraft to assist agricultural production. At present, plant protection activities (such as seeding, fertilization, pest control, etc.) have been carried out in airspaces below 120 m, and forestry protection management (such as fire monitoring, rain extinguishing, etc.) has been carried out in airspaces between 120 m and 300 m. The altitude of this airspace is very low, and the main aircraft used is unmanned aircraft (UAV). In the design of a UAV avionics system, we should focus on the design of video surveillance, video recognition, navigation path planning, and so on, in order to achieve the desired function of the aircraft.

3.3. Low-Altitude Operation Scenarios Supporting Modern Logistics

With the development of e-commerce, people gradually increased their dependence on logistics services, while the requirements for logistics services also gradually increased. In the past, the traditional logistics mode is more vulnerable to humans, weather, roads, and other aspects of impact, resulting in adverse results and affecting the development of the logistics industry. At present, aircraft are mostly used in cross-regional logistics operations. In a single city, the current use of aircraft for logistics transmission still needs to be developed. The use of aircraft in the city has specific height requirements, and in order to reduce the operating cost at low altitudes, most of them use unmanned aerial vehicles. UAV avionics systems need to focus on radio altitude, network communication, remote monitoring functions, and the development of ground network base stations.

3.4. Low-Altitude Operation Scenarios Supporting Urban Management

With the intensification of personnel density in modern cities, urban management is becoming more and more difficult. The use of low-altitude aircraft can help expand the management boundary of the city and achieve real-time, dynamic, and rapid responses

while changing the existing two-dimensional urban management mode, forming a new pattern of three-dimensional urban management. The use of low-altitude aircraft can quickly and in real-time achieve industrial production monitoring, urban security, road management, and so on. In this field, unmanned aerial vehicles are usually used, and the function design of image recognition and wireless link anti-interference of avionics system artificial intelligence should be focused on.

3.5. Low-Altitude Operation Scenarios to Support Transportation

With the advancement of urbanization, the scale of cities is increasing, the road traffic is becoming increasingly tense, and the flow of people in cities is becoming more and more frequent. In order to improve the ground traffic pressure in and between cities, the concept of a low-altitude traffic network is put forward in time, which achieves a 'point-to-point' low-altitude air traffic of people or goods through electric vertical take-off and landing aircraft. In this scenario, the avionics system of aircraft should focus on the development of air collision avoidance systems, wireless networks, video surveillance, and other system functions.

3.6. Low-Altitude Operation Scenario Supporting Intelligent Network Construction

If low-altitude aircraft can operate smoothly in low-altitude airspace, it is necessary to build a low-altitude intelligent network on the ground. The construction of a low-altitude intelligent network is the basic condition for achieving smooth operation of low-altitude aircraft. In addition to the corresponding intelligent network and digital service network on the ground, the corresponding technical configuration is also needed on low-altitude aircraft. Wireless transmission, aircraft network security, improved flight automatic control, and ground matching functions should be added to the low-altitude aircraft avionics system.

4. Design Requirements for Aircraft Low-Altitude Operational Avionics System Development of Research Questions

Aircraft in the operation process should follow the operation regulations formulated by the 'Civil Aviation Administration'. However, when the aircraft operates at low altitude, it has its own characteristics. According to the characteristics of low-altitude operation scenarios, the adaptability analysis of low-altitude aircraft design should be carried out, and the design work should be improved. Starting with the avionics system, which is closely related to the achievement of low-altitude operation functions, the low-altitude design requirements and low-altitude airworthiness requirements of aircraft avionics systems are analyzed.

4.1. Design Requirements of Avionics System for Low-Altitude Operation Mode of Aircraft

Commercial aircraft avionics systems now typically include flight management systems, modular integrated processing systems, integrated display systems, communication systems, navigation systems, air traffic control systems, air data systems, information systems, cabin systems, engine indication and cockpit warning systems, traffic collision avoidance systems, ground proximity warning systems, and data recording systems [8]. Avionics systems cover a very wide range of aircraft functions and basically cover the main electronic systems on the aircraft; therefore, avionics systems perform most of the core functions of aircraft control, such as communication, navigation, display, alarm, and so on. The development of an avionics system based on these functions generally follows the civil aircraft development process of ARINC ARP 4754A to carry out system design (see Figure 1) [9]. System design requirements are the basis of system development but also the key to system design, which should be focused on.

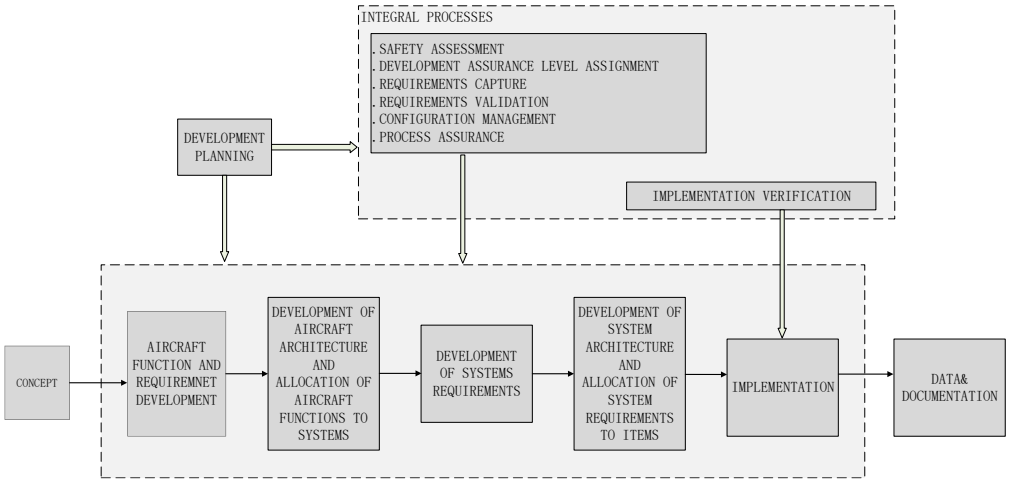

Figure 1. Aircraft/system development process.

When a commercial aircraft operates in the air, most of the functions of the aircraft's avionics system need to be carried out, regardless of whether it is a high-altitude or low-altitude or manned and unmanned aircraft. When performing the functions of the avionics system, there are still some differences between high-altitude and low-altitude and manned and unmanned aircraft. Commercial aircraft operated at low altitudes need some design requirements to achieve avionics function.

When a commercial aircraft operates at low altitude, the aircraft is always in the troposphere, the electromagnetic environment is complex, and the density of the low-altitude aircraft is high. As the main aircraft function system, avionics systems need to focus on the system's electromagnetic environment requirements, system network security of aircraft, accurate navigation, real-time data sharing between air and ground, and so on.

4.1.1. Design Requirements for Electromagnetic Environment of Avionics System

In the process of designing the avionics system of an aircraft, the electromagnetic endurance of system equipment should be fully considered from both active and passive aspects; the detailed electromagnetic requirements of commercial aircraft airborne system are given in the DO160G document [10]. The original conventional aircraft, basically, did not consider the complex electromagnetic environment on the ground but only started from the active electromagnetic radiation of the aircraft environment and carried out a certain airborne system electromagnetic endurance test. Therefore, the impact of the complex electromagnetic environment on the ground cannot be ignored for aircraft operating at a low altitude for a long time. Further, the design requirements of electromagnetic interference in complex environments should be added to the design of avionic systems of low-altitude aircraft, such as the electromagnetic compliance design requirements of ground radar, television wireless high-power networks, and so on.

4.1.2. Design Requirements for Network Security of Avionics System

Usually, when the aircraft is transmitting air–ground data, the avionics system needs to design the network security of the air–ground data transmission system to ensure the relative safety of the aircraft and will not invade the aircraft through the air–ground transmission link, thus causing serious consequences. In the past, only a few air-to-ground links were opened, such as data link systems, satellite communication, information systems, and so on. However, after the aircraft began to operate in low-altitude airspace for a long time, in order to interconnect the aircraft data, 5G, WIFI, and other commercial common networks were added. This required the enhancement of the network security design requirements of avionics systems, such as increasing the severity of hardware and software design to achieve functional systems.

4.1.3. Design Requirements for Precise Navigation

Usually, through the navigation function of the avionics system, the aircraft can achieve autopilot-based navigation, which greatly reduces the burden on the aircrew. Low-altitude aircraft are rich in variety, generally small in size, large in number, slow in speed, and strong in arbitrariness when flying in low-altitude airspace, which often makes the management of low-altitude aircraft out of control. In this regard, the characteristics of radio navigation, inertial navigation, and satellite navigation should be considered comprehensively when designing and planning the precise navigation function of aircraft in low-altitude airspace. Accurate, real-time, and dynamic navigation design are required on the ground. When several navigation modes are used synthetically, the functional requirements of avionics systems on low-altitude aircraft should be taken into account [11]. For example, the combination of satellite navigation and inertial navigation can be used in urban areas because of the interference of radio signals.

4.1.4. Design Requirements of Air–Ground Data Real-Time Transmission

Usually, when the aircraft is flying at a high altitude, in addition to the necessary ground and aircraft operation communications, the aircraft is basically in a relatively independent operation environment, and the data transmission does not affect flight safety if there is an appropriate delay. When the aircraft enters low-altitude airspace and operates here for a long time, the air-to-ground data of the system needs to be transmitted in real-time for the safety of operation, such as the operation of low-altitude unmanned aircraft. When the avionics systems of low-altitude operational aircraft carry out the real-time transmission of air–ground data, the delay time between airborne systems and between airborne systems and ground networks should be strictly defined; the redundancy design requirements should be defined to ensure the true and real-time transmission of air-ground data.

4.2. Airworthiness Requirements of Avionics Systems for Aircraft Operating at Low-Altitude Design

The existing system of general aviation low-altitude operation regulations and standards mainly includes three parts: first, low-altitude airspace air traffic management; second, low-altitude operation management; third, low-altitude service guarantee management [7]. Based on the basic requirements of general aviation low-altitude operation, low-altitude flight aircraft must meet the corresponding four types of airworthiness requirements. First, the general rules of operation and flight. Second, the airworthiness requirements of airborne equipment required for low-altitude flight, civil aviation products and parts certification provisions, and civil aviation materials, parts, and airborne equipment technical standards provisions. The third is the special regulations for civil aviation technical standards in low-altitude airspace, and the fourth is the revision and improvement of the training outline for the main professional technical qualified personnel such as flight, maintenance, air traffic control, and safety supervision in terms of professional license and qualification approval [12]; see Figure 2. In this paper, according to the design characteristics of avionics systems in low-altitude aircraft, the relevant airworthiness requirements of avionics system design are put forward.

In the design of avionics systems, considering the characteristics of a low-altitude operation scene, as well as the design characteristics of aircraft in electromagnetic, air-ground data interaction, accurate navigation, and so on, it is suggested that some adaptability requirements should be added to the corresponding technical standards of airborne equipment.

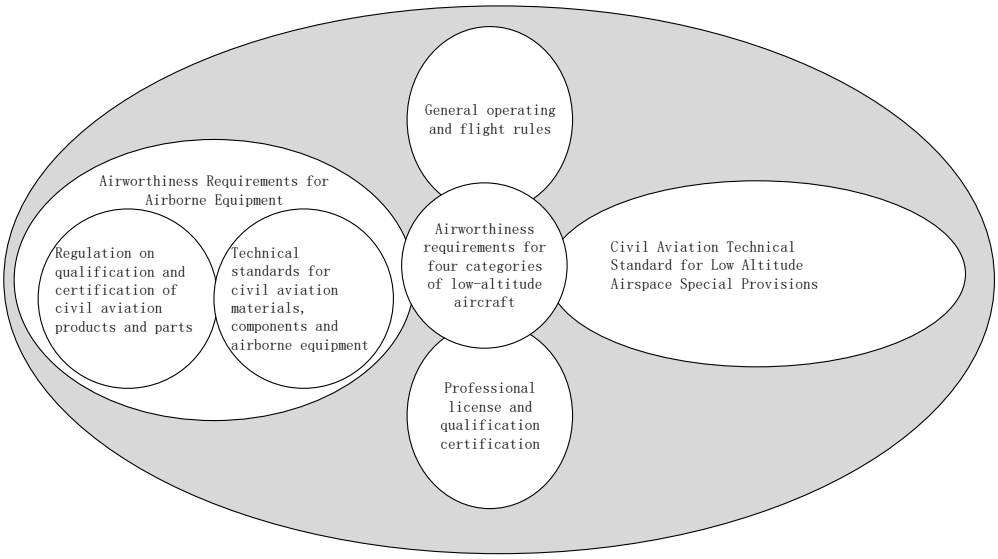

Figure 2. Airworthiness requirements for four categories of low-altitude aircraft.

4.2.1. Electromagnetic Requirements for Airborne Equipment of Avionics System

The system or equipment shall have the ability of anti-jamming, no system function failure, and no system function degradation when performing aircraft-level or system-level functions in the low-altitude-specific high-intensity radiated field (HIRF) area. Because the avionics system is responsible for the main functions of aircraft control and display, if in low-altitude flight, according to the previous requirements, it can fail for a short time and then resume its function after leaving the high-intensity radiation field (HIRF) area. It is possible that the aircraft will not have the opportunity of fault tolerance and correction in low-altitude flight since some low-altitude aircraft are unmanned, but the system is out of control or degraded; it will directly affect flight safety.

4.2.2. Airborne Design Air–Ground Data Interaction Requirements for Avionics System

When the system or equipment performs aircraft-level or system-level functions in low-altitude scenarios, the installation location should be clear so that it cannot adversely affect the implementation of air–ground data transmission. Because the previous airworthiness installation requirements only indicate that the failure impact caused by the installation is acceptable, there is no clear constraint on specific scenarios. When low-altitude aircraft fly at low altitudes, especially unmanned aerial vehicles, the air–ground data interaction is more closely than before; therefore, it is necessary to clearly put forward further guidance on the implementation of air–ground data interaction function equipment.

4.2.3. Airborne Equipment Network Security Requirements

The system or equipment shall be capable of preventing any intentional or unintentional alteration of software or data in the aircraft control (network) domain and the operations information service (network) domain from other network domains while performing aircraft-level or system-level functions in low-altitude scenarios. Because the aircraft and the ground wireless networks are always in a state of networking when the aircraft operates in low-altitude scenarios, there is an exposure risk for the system or equipment. There is no clear requirement in the previous airworthiness requirements; therefore, it is necessary to supplement the corresponding airworthiness provisions to regulate the design work of the aircraft.

4.2.4. Precise Navigation Requirements for Aircraft

The system or equipment should be able to accurately locate the aircraft in accordance with the operating rules for low-altitude airspace when performing aircraft-level or system

functions in low-altitude scenarios. The density and height stratification of aircraft in low-altitude operation scenes are different from the past; through the analysis of the characteristics of low-altitude operation, the aircraft needs further clear airworthiness requirements in precise navigation.

5. Discussion and Conclusions

With the development of the low-altitude aircraft market and the clarity of the national policy of low-altitude operation, the low-altitude economy will inevitably have an explosive development. Further, based on the low-altitude economic application scenario, low-altitude aircraft have a development direction. The avionics system on low-altitude aircraft will become the focus of the system manufacturers, but the design and airworthiness of the avionics system will face new problems in the low-altitude operation environment. In this paper, based on the existing aircraft avionics system design airworthiness experience, the avionics system design airworthiness recommendations for low-altitude operating environments are proposed. With a large number of commercial operations of low-altitude aircraft, there is still a lot of compliance work to be completed in the design of aircraft avionics systems. For a long time in the future, the design and airworthiness of low-altitude aircraft need the joint efforts of scientific and technological workers to establish and form a reasonable system to ensure the market application of low-altitude aircraft.

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